Improving Physics Instruction by Analyzing Video Games

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Video games can be very powerful teaching systems, and game designers have become adept at optimizing player engagement while scaffolding development of complex skills and situated knowledge. One implication is that we might create games to teach physics. Another, which I explore here, is that we might learn to improve classroom physics instruction by studying effective games. James Gee, in his book What Video Games Have to Teach Us About Learning and Literacy (2007), articulates 36 principles that make good video games highly effective as learning environments. In this theoretical work, I identify 16 themes running through Gee's principles, and explore how these themes and Gee's principles could be applied to the design of an on-campus physics course. I argue that the process pushes us to confront aspects of learning that physics instructors and even physics education researchers generally neglect, and suggest some novel ideas for course design.

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Article:

*****Note: Full text of article below**

Improving Physics Instruction by Analyzing Video Games

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INTRODUCTION

In any domain, thinking outside of the historical "box" that one is within—challenging implicit assumptions and verbalizing deeply-held models—is difficult. I believe that collectively, all of us are stuck within a box of assumptions and models about what physics instruction, and what schooling in general, should look like. PER-based innovations chip away at the walls of the box, but rarely introduce dramatically new and paradigm-shifting perspectives. A provocation from far outside our domain can help us to imagine possibilities that lie beyond the box, opening up the idea space that we explore in PER.

Recently, scholars have taken note of the power of video games to engage people in lengthy, challenging, sometimes frustrating activity rich in model-building and problem-solving; to teach complex skills; to catalyze strong peer-support communities; and even to provoke reflection upon values and identity [1-7]. James Gee has argued that good video games are in fact carefully engineered learning machines:

> Game companies face an interesting problem, a problem that schools face, as well: how to get someone to learn something that is challenging and requires persistence… If people can't learn to play a company's games, the company goes broke. So game designers have no choice, they have to make games that are very good at getting themselves learned. [6]

One possible response to this observation is to design video games that teach physics. Another is to "gamify" instruction, dressing it up with the superficial trappings of games. A third, which I advocate, is to learn from video game design so as to improve in-person instruction in deep ways.

In *What Video Games Have to Teach Us About Learning and Literacy* [7], Gee analyzes a range of video games to extract 36 principles that game developers employ. He argues that these principles are consonant with modern perspectives in the learning sciences, that they can be fruitfully applied to the teaching of traditional academic subjects, and that in many ways game designers are ahead of schools in the sophistication of their instructional approaches. Gee generalized his principles so as to apply to academic learning, not just video games; in this paper, I explore their implications for physics instruction, in part by identifying themes that run through them and challenge our current approaches. I see this as a first step towards the development of a videogame-inspired theoretical framework for characterizing extant and possible learning environments, a framework that should complement existing PER theories by helping us envision new ways to explore and optimize the learning dynamics they describe. Whether or not we can apply all of Gee's principles to our discipline, the exercise of trying should stimulate new ideas for both research and instruction.

BACKGROUND: GEE'S PRINCIPLES

Some of Gee's 36 principles align well with current PER-based perspectives and practices. His *active, critical learning principle* (#1) states that "All aspects of the learning environment… are set up to encourage active and critical, not passive, learning"—what PER calls "active learning." His *semiotic principle* (#3) states that "Learning about and coming to appreciate interrelations within and across multiple sign systems (images, words, actions, symbols, artifacts, etc.) as a complex system is core to the learning experience"—what PER describes as "using multiple representations." His *probing principle* (#15) states that "Learning is a cycle of probing the world (doing something); reflecting in and on this action and, on this basis, forming a hypothesis; reprobing the world to test this hypothesis; and then accepting or rethinking the hypothesis"—a principle deeply embedded in inquiry-based approaches such as ISLE [8].

Other principles address topics generally neglected by PER. Gee's *design principle* (#2) claims that "Learning about and coming to appreciate design and design principles is core to the learning experience." Gamers can often extend, modify, or add depth to a game world; what can they "design" in physics? Experiments? Scientific arguments? Models and theories? Learning experiences? We tend to focus more on having students develop competence with things that "experts" have designed. Similarly, Gee's *intertextual principle* (#19) claims that "The learner understands texts as a family ('genre') of related texts and understands any one such text in relation to others in the family…" Even PER-informed courses typically provide students with one canonical course textbook, and aside from graduate-level research seminars rarely ask students to digest and interrelate a family of texts (reference books, journal articles, web resources, etc.).

Some of the principles that Gee extracts from video game design seem to challenge fundamental structures and assumptions of schooling, the content and learning goals of physics courses, or both. His *identity principle* (#8) asserts that "Learning involves taking on and playing with identities in such a way that the learner has real choices (in developing a virtual identity) and ample opportunity to meditate on the relationship between new identities and old ones…" Although physics students are in principle constructing identities as future physicists, we rarely make that explicit to them, and even more rarely design instruction to address the dynamics and requirements of identity development. (Some recent PER work has begun exploring variables relevant to identity development [9,10].) Conceiving of physics education as *primarily* a project in identity development, and only *secondarily* in skill and knowledge development, might lead us to some very different instructional models and practices.

Gee's *amplification of input principle* (#10), "For a little input, learners get a lot of output," is also challenging. By "output," he means immediate, direct, pleasurable reward. In the context of a video game, that can be an entertaining graphical display, access to a new portion of the game world, provision of new tools or capabilities, or the like. In much of physics learning, students receive little reward beyond grades and a vague, uncertain, and slowly increasing sense of "getting it." What kind of immediate "rewards" or "output" beyond instructor confirmation might be possible for physics learners, and what would these require of learning modalities and class structures?

Gee heavily stresses his *situated meaning principle* (#17): "The meanings of signs (words, actions, objects, artifacts, symbols, texts, etc.) are situated in embodied experience. Meanings are not general or decontextualized. Whatever generality meanings come to have is discovered bottom up via embodied experiences." For Gee, reading a book, listening to a lecture, participating in a class discussion, or completing a tutorial worksheet are relatively meaningless unless situated in a meaningful, goal-driven context of action in which the learner is trying to accomplish something perceived as "real." This connects to his *text principle* (#18), "Texts are not understood purely verbally… but are understood in terms of embodied experiences. Learners move back and forth between texts and embodied experiences. More purely verbal understanding (reading texts apart from embodied action) comes only when learners have had enough embodied experience in the domain and ample experiences with similar texts." It is clear from his discussion of these principles that solving arbitrary physics problems, whether in the context of homework, tutorials, or classroom response system polling, do not by themselves constitute "embodied experience." Hands-on inquiry-driven curricula like ISLE [8] and *Modeling Instruction* [11] are more promising in this regard. ("Embodied" is not synonymous with "kinesthetic." The question of what exactly might constitute such experience within physics learning deserves careful exploration.)

ANALYSIS: THEMES

Taken as a whole, Gee's 36 principles provide a provocative framework for challenging our instructional models and assumptions, for identifying our blind spots, and perhaps for suggesting radical alternatives. As I pondered how each principle might apply to physics instruction, I found certain themes recurring across multiple principles. A preliminary thematic analysis led me to tentatively identify 16 themes, each connecting to 8±5 of Gee's principles. In this section, I present three that I believe pose great challenges and opportunities for PER and physics instruction, list the other 13, and present one overarching meta-theme.

<u>Assessment</u>: Video games assess players almost continuously, but quite differently than do schools. Game assessments provide players with continual feedback on their ability to complete meaningful, contextualized, authentic (to the game scenario) tasks, in a

low-stakes way that encourages risk-taking and makes failure nonthreatening and informative. In fact, assessment is generally indistinguishable from learning via exploration and experience. Players can often choose when and on what competencies they will be assessed by the challenges they take on. Feedback is immediate and entertaining, making failure fun (or at least not too discouraging) and success invigorating.

In contrast, most physics students are assessed intermittently, at times and on topics beyond their control. They can rarely perceive success or failure through the direct effects of their efforts, but must wait (often days) to be told whether their problem solution or lab analysis is correct. Most assessment comes after learning, rather than during it, and therefore cannot provide useful guidance. Each failure has a permanent effect on averaged grades. Some recent attempts at assessment reform (e.g., "standards-based grading" [12]) allow later success to expunge early failure, and many PER approaches stress rapid formative assessment, but such attempts cannot by themselves integrate assessment with exploration, discovery, and learning as thoroughly as do video games.

Authenticity: Video games rarely make a distinction between learning and being: One develops the knowledge and skills necessary to *be* a certain kind of individual within the game world by engaging in activities and pursuing goals authentic to that kind of individual. One rarely undertakes extensive training before beginning to play game; one simply begins to play. Early game levels are designed to orient the player and gently introduce requisite skills. Even at the outset, learning occurs in a subset of the real domain, with skills developed in context rather than in isolation. The nature, goals, affordances, and consequences of the learning activities are authentic to the "profession" one is trying to learn.

In most physics instruction, however, students do not develop knowledge and skills through the practice of physics. Students are presented with relatively unmotivated content knowledge that "will be useful someday," and assessed via arbitrary, decontextualized tasks ("problems") that bear very little resemblance to the activities a real physicist engages in. Even when a physicist solves a problem ("does a calculation"), most of the art lies in defining a problem that models some system and meets some larger objective, successively evolving the problem to explore the model, interpreting the results, and drawing conclusions. Typical school assessments are bounded in unrealistic ways, through artificial constraints on time, collaboration, tool use, and resource consultation. As Redish has observed [10], physics instruction rarely makes explicit the "hidden curriculum" of the subject.

Identity: The theme of *authenticity* ties to the theme of *identity*, articulated precisely in Gee's *identity principle* (above) and running through several of his other principles. Good video games are not just about *doing* stuff; they are about *becoming* someone, with all that entails: knowledge, skills, tools and resources, goals, values, cultural models, fluency in a semiotic domain, participation in an affinity group, meaningful choices with consequences for one's identity, and the ability to design, create, and otherwise contribute to the construction of a domain rather than merely learning about and experiencing it. Even solo games are generally embedded in a social environment of peers, internet-based support communities, add-on tools for "modding" games to customize or extend them, and player-written fiction set in the game world. Gee highlights the fact that in many games, players can deliberately choose to explore and experiment with different identities, and tend to develop pride in identities constructed over time.

Some elements of a current physics student's program might implicitly address aspects of identity development. Summer internships, advanced laboratory courses, and journal-based seminars might allow students to engage in select aspects of "being a scientist" within a community of practice. A few students find sympathetic faculty mentors to interact with informally over time, asking questions, observing, and generally witnessing what being a physicist entails. Such experiences are the exception rather than the rule, however. They are typically "add-ons" to a physics program, rarely planned, coordinated, or integrated with the bulk of content learning. Most critically, they rarely invite students to consciously explore and choose from a range of possible identities.

Other themes running through Gee's principles include *asynchrony*, the ability of different players to develop mastery at their own pace; *collaboration*, coordinating effort with others in order to master larger challenges; *exploration* and discovery as the primary mechanism of learning; *feedback* through a variety of immediate, direct, natural, and intrinsically motivating mechanisms; *grounding* of learning in a rich, concrete world of embodied experience; *motivation* through intrinsic rewards and achievement rather than external or artificial consequences; a rich web of diverse *objectives* that envelop and support "content" learning; *personalization* of goals, learning, and activity; deep focus on learning the *process* rather than merely the content of the domain; frequent *reflection* on learning and self, on various levels; development of fluency with multiple *representations*; the provision and accumulation of a range of *resources* that both support learning and become part of the learner's "distributed" or "situated" knowledge; and extraordinarily sophisticated *staging* of the learning process so that foundational skills are developed early, resources are discovered "just in time" for use, tools are found that offload mastered tasks to free cognitive capacity for new concerns, and difficulty stays right at the edge of the learner's capacities (with aid from with real and virtual allies).

Agency: At a yet higher level, I find a strong meta-theme underlying and unifying many of these themes, that of learner *agency*. Perhaps the most dramatic difference between video game learning and school-based learning is that most video games provide players with a strong sense of being in control of their destiny, both within game play and in how they choose to interact with the game and with its associated communities. Players can often choose their identities, their values, their goals, the skills they develop, the tasks they undertake, the peers they cooperate with, and the forms of extra-game participation they engage in. They can almost always choose when to play, how intensively, and for how long. The choices they make have visible, often epic consequences for the game world. Perhaps most importantly, nothing is irrevocable: A player can always wipe out failure, or even unsatisfactory choices, by trying again. Good games are very effective at convincing players that they *can* eventually develop mastery, no matter their initial facility. In contrast, physics learning looks much more like something we inflict on students than something that they pursue and control.

DISCUSSION

To me, themes of *grounding*, *exploration*, *assessment*, and *feedback* suggest that we ponder how the process of learning physics can be re-conceived in such a way that students learn physics by encountering and exploring some experiential "terrain" in which physics ideas are manifest, receiving immediate, obvious, and natural feedback about their developing understanding and competencies. One key ingredient for making feedback immediate and apparent, in a manner that scales, might be the development of students' self-assessment capacities in parallel with content learning. Students must learn to self-check and peer-check in the same way that practicing scientists do. A second ingredient might be the development of a collection of physical equipment that can provide "embodied experience" to ground students' learning, with theoretical development always linked to concrete activity. Can we devise a "landscape" of hands-on explorations (not planned experiments) that naturally suggests, develops, and self-corrects students' understanding of physics? (*Modeling Instruction* [11] aspires to this, but falls short of the extreme ideal I am suggesting.)

The themes of *authenticity* and *identity development* suggest that we reframe physics instruction as "becoming a physicist" (or a scientist or engineer or etc.) rather than "learning to solve physics problems." This is no whitewash, and requires a deep rethinking of our entire curriculum. As one hypothetical possibility, consider an alternate-history Modern Physics course in which students construct alter-egos as fictional physicists at the dawn of the 20th century, forming research groups, performing experiments, devising and refining models, and writing articles as they come to terms with new phenomena and ideas. In this alternate history, the transition from classical to modern physics would unfold over the course of the semester, with students' characters playing a seminal role, and the instructor introducing provocative new results and theories along the way (perhaps through "non-player characters" representing historical figures). In addition to grappling with the new physics, students would have to develop requisite mathematical, experimental, and research-process skills. They would develop a sense of what "being a physicist" is like and how physics unfolds as a living domain. They could also be confronted with choices about what kind of physicist they want their character to be: How carefully do they substantiate their claims before publishing? What philosophical biases do they privilege? What research specialties and styles do they develop?

Based on my preliminary analysis of Gee's principles and of the gap between them and the characteristics of even the most PER-influenced physics instruction currently extant, I claim that viewing physics instruction through their lens and seeking ways to better implement them is likely to stimulate theoretical and practical advances—regardless of exactly how the domain of physics might differ from the "content" of game learning.

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